RETARDATION OF COMBUSTION THROUGH WIRE SCREENS IN CLOSED PIPES

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THE RETARDATION OF COMBUSTION THROUGH WIRE SCREENS IN CLOSED PIPES

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OBJECT.

This investigation is confined to the use of explosive mixtures of illuminating gas and air, at approximately atmospheric pressures and room temperatures, at rest in closed 4-inch wrought iron pipe and fittings. These conditions were arbitrarily chosen; the apparatus is designed with the end in view of permitting a more extensive study of the subject by varying these conditions, if such a continuance be deemed advisable in succeeding years.

The subject matter of this thesis has been divided into five parts:

Part one,

Introduction, and statement of trade customs in the manufacture of wire screens.

Part two,

A statement of the problem. Method of using screens today.

Part three,

Description, construction and calibration of apparatus.

AN ACKNOWLEDGMENT.

The authors desire to express their gratitude to Professor Joseph B. Finnegan and Mr. Hamilton Allport, whose efforts and co-operation make this report possible.

We also are indebted to the staff of the Underwriters' Laboratories for helpful suggestions made in this thesis and for the use of Laboratory equipment.

Kenneth V. Hall　　　　Frank J. Conway.

May 31, 1917.

Combustion Retarding Apparatus.

TABLE OF CONTENTS.

Combustion Retarding Apparatus.

LIST OF ILLUSTRATIONS.

PART 1

Introduction, and Statement of Trade Customs in the Manufacture of Wire Screens.

Combustion Retarding Apparatus.

INTRODUCTION.

The first person to employ the known phenomenon, that combustion will not pass thru the mesh of fine wire screens, was Sir Humphry Davy. The Davy lamp consists essentially of a wire screen cylinder surrounding the flame of an ordinary miners lamp. The gas passes thru the meshes to supply the flame but the flame does not flash out thru the meshes when in the presence of explosive mixtures of gas and air. The presence of this mixture is detected by the sputtering of the lamp. Close observation will show tiny flames just inside the screen which die out before passing thru the mesh. The cooling properties of the wire screen cool the flame below the kindling point and hence the flame dies. The limiting size of the openings and the size of wire have not been determined.

The mere statement of the mesh of a wire screen will not identify it. There are certain

customs observed in this industry which we will quote from the catalogue of the F.P.Smith Wire & Iron Works, Chicago, Illinois.

Combustion Retarding Apparatus.

Terms and Customs of the Wire Cloth Industry.

Warp and Filling Warp wires are those which run longitudinally in the cloth. Filling wires run transversely in the cloth and cross alternately over and under the warp wires. In describing cloth the warp mesh and wire precede, in their respective positions, the same elements of the filling. Thus 9 x 8 mesh No. 18/19 wire indicates that the warp has 9 meshes per lineal inch and is made from No. 18 wire; and the filling has 8 meshes per lineal inch and is made from No. 19 wire.

Mesh The size of any mesh in wire cloth is the distance from the center to center of its parallel wires- not the clear space between these wires. The numeral which precedes this word in the description of the cloth indicates the number of openings it has in one lineal inch. Thus 4 mesh means that the cloth has 4 openings per lineal inch, each measuring

1/4" from center to center of its parallel wires.

The clear space between the wires is determined by the size of the wire used in the cloth and is found by deducting the diameter of one of its wires from the size of the mesh. Thus, if No.16 steel wire (which is 1/16" diameter) were woven into 4 mesh cloth, it would show 3/16 inch clear space, or 1/4 inch (size of mesh) less 1/16 inch (diameter of wire).

The filling meshes in many of the very fine grades, and also in some of the medium ones made from the largest wire that can be woven in each, are somewhat larger than the warp meshes because it is impossible to force wire beyond a certain point without straining it and impairing its efficiency.

Space — This term, or as it is sometimes expressed "hole" or "opening", means clear

space between adjacent wires, and its size is not effected by the diameter of the wire used in the cloth. This cloth of 1/4 inch space will allow material 1/4 inch in diameter to pass thru it regardless of the size of wire from which it is woven.

Wire Gauges The recognized standard for gauge wire fabrics are the old English gauge for Brass, Copper and Bronze wire. The diameters of all sizes of this standard, expressed in decimals of an inch, are shown in accompanying comparison table.

It is deemed advisable to make all wire measurements with a micrometer caliper, for great accuracy.

In all kinds of commercial wire there is a slight variation which is more frequently over size than under diameter specified by the standard under which it is classified; and in weaving fine sizes, particularly of soft materials, the tension

to which they are subjected in the loom tends to elongate them and slightly reduce their diameters.

The Wire-Cloth Manufacturers' Association adopted the old English Gauge as the Standard for all brass or copper wire cloth.

COMPARISON OF VARIOUS METAL GAUGES.

No. of Gauge	Old English	U.S. Standard	American	No. of Gauge
20	.035	.0375	.0320	20
21	.0315	.0344	.0285	21
22	.029	.0313	.0253	22
23	.027	.0281	.0226	23
24	.025	.0250	.0201	24
25	.023	.0219	.0179	25
26	.0205	.0188	.0159	26
27	.0188	.0172	.0142	27
28	.0165	.0156	.0126	28
29	.0155	.0141	.0113	29
30	.0138	.0125	.0100	30
31	.0123	.0109	.0089	31
32	.0113	.0102	.0080	32
33	.0103	.0094	.0071	33
34	.0095	.0086	.0063	34
35	.009	.0078	.0056	35
36	.0075	.0070	.0050	36

PART 2.

A Survey Regarding the General Principles and Important Factors Entering Into the Study of Retardation of Combustion Thru Wire Screens in Closed Pipes, Together with a Summary of the Methods of Using Wire Screens Today.

Combustion Retarding Apparatus.

A STATEMENT OF THE PROBLEM.

The widespread use of Gasolene and its related products has built up the demand for some safe way to store these commodities. It has been thought by investigators that the placing of a wire screen or a perforated plate in the vent pipe would prevent the passage of combustion into this storage tanks. The problem then resolves itself around the law of cooling and radiation as applied to the screen and pipe itself. The probability of the combustion flashing back is influenced by the ignition temperature of the gas, richness of explosive mixture, calorific value of the gas, specific heat of gas and air and the specific heat of the products of combustion.

It is a well known fact that gases and vapors in general are not actually explosive except when mixed with air or oxygen and then only when the mixture is in definite proportions.

Combustion Retarding Apparatus.

Combustible gases and vapors can not furnish an explosion on ignition, unless the air with which they are mixed contains just sufficient oxygen, neither less nor more, and this quantity differs for each gas or vapor. The explosive range of the gas used was from 7 to 17%, having a maximum explosibility between 14.5 and 15%.

The following problems present themselves:

Method of determining the proportions of gas and air.

Method of igniting the mixtures.

Temperature and Pressure measurements.

Producing pressures below atmospheric.

Removal of the gases after each combustion.

Method of determining whether the combustion passes thru the screen.

The means by which these problems were solved are explained clearly in Part 3.

Combustion Retarding Apparatus.

FILL AND VENT FITTING AS USED ON STORAGE TANKS.

The fill pipe for an underground storage tank can not be opened without simultaneously opening the vent pipe. Fill and Vent openings are provided with screens. Each fitting is placed directly in a flange provided in the underground storage tank; the inner or fill pipe of the combination fitting extends below the outer or vent pipe so that the issuing vapor will not trap the incoming liquid. Details of construction are shown by figure 1 for the combined filling and venting fitting which is used when the tank is not permanently vented. If the tank is permanently vented with a suitably protected vent pipe as required in some localities, all that is necessary for the filling pipe is a properly locked and screened pipe, which is accomplished by having a simple two inch vent provided with a locking and closing mechanism as shown in figure 1 and equipped with a screen as

Combustion Retarding Apparatus.

shown by the same drawing but with a wider flange so that it will hang on the top of the outer pipe.

PART 3.

Description, Construction and Calibration of Apparatus.

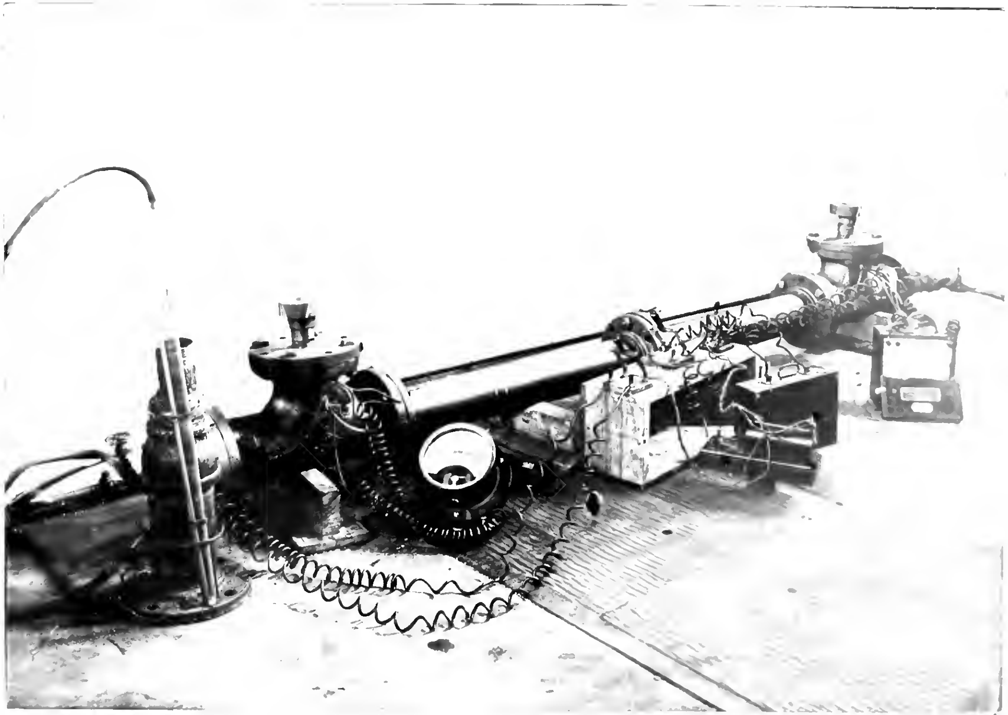

FIG. NO.2 THE COMPLETE APPARATUS.

Combustion Retarding Apparatus.

DESCRIPTION OF APPARATUS.

The writers have endeavored in this experiment to reproduce conditions which would most likely arise in standard pipe lines.

The details of the apparatus are shown by figure 2 and consists of two combustion chambers, two lengths of standard pipe with flanged ends, for screen insertion, two observation ports and flanges of special design, two specially designed and sensitive thermo-couples, two end flanges of special design, containing taps for spark plugs, gas and air vents, relief valve, manometer and aspirator connections.

The following is a list of the standard pipe fittings used:

2- 4" Tees.
4- 4" Flange Couplings.
2- Pieces 4" pipe 24" long.
1- 3/8" cross.
1- 1" cross.
2- 9" blind flanges with 2" top.
2- 2" observation ports.

Combustion Retarding Apparatus.

1-9" blind flange with 1/2" and 3/8" taps.
1-9" blind flange with 1/2" and 1" taps.
2 Thermo Couples.
2 Millivoltmeters.
4-3/8" Globe Valves.
1-3/8" Pet cock.
2-3/8" - 1/4" adapters.
1-1" relief valve.
1-2" Globe Valve.
2-2" Gate Valve.
1-Aspirator, 6" pipe.
  Gas Connections.
  Air Connections.
2-1/2" Spark Plugs.
1-Mercury Manometer.
1 Pressure Gauge.
  Samples tested.

Combustion Retarding Apparatus.

CONSTRUCTION.

Observation Ports — The observation ports were of special design made by the writers and are shown in figure 3. A solid piece of cast iron was machined to fit a 2" pipe union connection. A 3/8" shoulder was made, leaving an opening 1-1/2" in diameter. This shoulder produced a sufficient bearing surface for the plate glass, which was 3/8" in thickness. The glass was placed between two rubber gaskets, giving an air tight joint.

Thermo-Couples — Combustion was detected by the use of two sensitive thermo-couples serving as detectors, made by the writers. Each couple consisted of four junctions, two hot junctions inside the pipe, and two cold outside of pipe; the two cold junctions were connected to millivoltmeters. The couples were made of No.26 Copper-Nickel

Combustion Retarding Apparatus.

(Advanced Wire) and No. 25 copper wire. They were fused in an electric arc. The sensitiveness of the couples was first tested by the application of flame and a large deflection was obtained on a millivoltmeter. They were then tested by the blowing of the breath upon the couple, which produced an appreciable deflection, thus assuring their sensitiveness in detecting combustion in the closed pipe. The couples were placed in a 1/2" pipe with a right angle bend at outside end. The space not occupied by the thermo-couples thru the pipe was filled with plaster of paris. The object of the right angle bend was to avoid the blowing out of the plaster of paris, by the force of the explosion.

The couples were placed two and one-half feet from the faces of the screen, thus producing a deflection only when they were in actual contact with a flame, and not producing a deflection by radiation of heat thru the sample.

Combustion Retarding Apparatus.

End Flanges The end flanges were originally two blind flanges. The head flange was tapped for 1/2" spark plug and a 3/8" tap for connections to gas, compressed air and manometer. The rear end flange was tapped for a 1/2" spark plug and a 1" tap for relief valve, gas and aspirator. The flanges were bolted on air tight. These are shown in figure 3.

Inserting Screens The problem of inserting screens was solved by the use of rubber gaskets on each side of screen. Bolt holes were cut in the screen to correspond to bolt holes in 9" rubber gaskets. Great care was exercised in inserting screens so that the mesh would not be distorted. In this manner an air tight joint was easily obtained.

Aspirator The aspirator as shown in figures 4 and 5, consisted of a 6" standpipe,

Combustion Retarding Apparatus.

6' high and was connected to the rear end of the apparatus. The aspirator was filled by a 2-1/2" connection to the city water main and a 1" over-flow pipe installed at the top. This over flow pipe indicated when the aspirator was filled and also prevented water from running into the combustion chamber.

Reduced pressures were produced by shutting off the over flow pipe and opening the discharge pipe at the bottom. A pressure difference up to 6" of mercury could be obtained with one filling of the aspirator.

Spark Plugs

The spark plug on the head end was of a special design with a pet cock attachment. This pet cock permitted a current of fresh air to flow thru the system with the suction line open, thus driving out all of the unburned gases and all products of combustion. The rear end spark plug was of plain construction. These

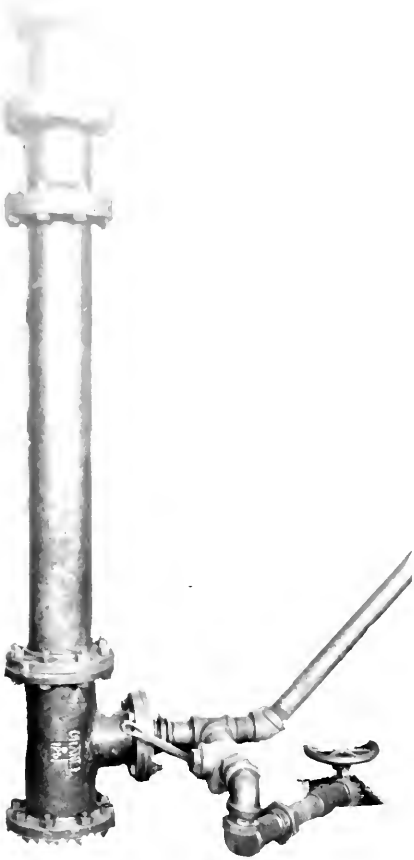

FIG. NO. 4 THE ASPIRATOR.

Combustion Retarding Apparatus.

were used as a source of ignition for the gaseous mixture. The specially designed spark plug is shown in figure 5.

Relief Valve The relief valve was used to take care of the excess pressure produced during the combustion. Drawing of the relief valve is shown in detail in figure 5.

The valve employed was made of brass. It consists of a conical valve, seating into a valve opening, and held closed by a spring. The tension of the spring could be regulated by a knurled plug at the top of the valve. The valve screwed into a 1" standard pipe tap in the rear flange.

Manometer A 24" U shaped manometer was used. The liquid was mercury. With this manometer, the difference in level of the two legs, and by reference to curve No.3 the desired percentage of gas was obtained, and by referring to

Combustion Retarding Apparatus.

curve No.5 the desired volume of air could be expelled by noting the manometer reading. It was also feasible to ascertain the air tightness of the system by introducing a difference in pressure between the system and the atmosphere and observing how much loss in pressure would take place in a given time. One leg of the manometer was connected to the apparatus and the other leg left open to the atmosphere. The difference in reading on the manometer shows the difference in pressure of the combustion chamber and atmospheric pressure.

Induction Coil An induction coil as shown in figure 6 was connected to a storage battery thru its primary coil and the secondary to the spark plug.

Combustion Retarding Apparatus.

CALIBRATION OF APPARATUS.

Volume The volume of the apparatus was determined by water displacement. The joints were painted and made tight, and the blind flanges bolted on the ends. Water was poured into the observation port with a standard U.S.Gallon measure and a graduated flask. The apparatus was found to contain 24,430 c.c.

Gas-air Mixture Assuming that gas and air are chemically inert, the following method was used for determining the percentage mixture:

Let V_1- Volume of system in c.c. below atmospheric pressure.

P_1- Pressure of V below atmospheric.

V_2- The volume of air plus gas in c.c. subjected to pressure P_2.

P_2- Atmospheric pressure.

$V_3 = V_2 - V_1$ or volume of gas in c.c. to be added to the system.

Combustion Retarding Apparatus.

The temperature remaining constant. Let the volume of system be V_1 at P_1 and V_2 at P_2, then $P_2 = \frac{P_1 \times V_1}{V_2}$. Since the system is rigid there must be added a certain volume to make up the difference between V_1 and V_2. This volume is V_3 or the amount of gas in c.c. to be added to V_1 to bring it to V_2.

Sample Calculations.

$$V_3 = V_2 - V_2$$

$$P_1 = \frac{P_2\ V_2}{V_1}$$

$V_1 =$ 24,430 c.c.

.07 x 24,430 = 1,710 c.c. = V_3

24,430 - 1,710 = 22,720 c.c. = V_3

P_2 = 14.7 # sq.in.

$$P_1 = \frac{14.7 \times 22{,}720}{24{,}430}$$

P_1 = 13.67 # sq.in.

14.7 - 13.67 = 1.03 # sq.in. press.loss.

1.03 x 2.03 = 2.12 in. Hg. for 7% Gas.

Combustion Retarding Apparatus.

Leakage Test The apparatus was tested for leakage by filling with water and admitting compressed air. Where any of the water leaked out, marks were made, the apparatus drained, all leaky joints were painted and tightened. The system was finally tested by the use of the manometer and aspirator. All the valves were closed. The aspirator was turned on and a difference of level of mercury was obtained. The aspirator was then shut off the difference of mercury in the two manometer arms remained constant, thus showing that the system was air tight. This proceedure was carried out at each insertion of a new screen.

PART 4.

DESCRIPTION OF TESTS.

RESULTS.

Combustion Retarding Apparatus.

DESCRIPTION OF TESTS.

All of the valves connected with the system are closed tightly at the start. First open the exhaust valve leading to the aspirator then open the gas inlet, shown in figure 7, allowing the gas to run for one minute. This will clear out any air that may have been in the gas lines attached to the system. Close the gas inlet. The aspirator is now filled with water from the city main, and all of the gas that is in the system may be removed by filling the aspirator several times. To facilitate the replacing of the gas by air, the observation port on the head end is removed.

The system is now ready for the introduction of an explosive mixture. The observation port is replaced in its original position and all valves closed. The valve to the manometer is opened and the aspirator allowed to drain until a difference in reading of 2.1 in. Hg. is observed, by referring

Combustion Retarding Apparatus.

to curve No.3 shows a mixture of 7%. The aspirator valve is now closed and the operator on the rear end allows gas to enter the system until the pressure difference is reduced to 1.05 in. Hg. Then the operator on the head end admits gas into the combustion chamber until the manometer shows no difference in pressure . This indicates the system is under atmospheric pressure. All valves are now tightly closed and the gas allowed to diffuse for five minutes.

The gas at the head end is ignited by means of the spark plug. The combustion may be noticed thru the observation port and also be determined by the galvanometer deflection.

If the combustion passes thru the screen, the galvanometer on the rear end will show a deflection and the combustion may be seen thru the observation port.

If the combustion does not pass thru the sample, the spark is applied on the rear end,

Combustion Retarding Apparatus.

as shown in figure No.7, and the combustion can be observed thru the port hole and the presence of flame also indicated by a deflection of the galvanometer.

If we secure no combustion on this second trial, then it is readily known that there was not an explosive mixture in that portion of the pipe. Whenever this occurs another test should be made using the same percentage mixture.

After the combustion, the manometer valve is opened and a reading taken of the decreased volume,- by reference to curve No.4, this amount may be ascertained. This reading will show if complete combustion took place. Its reading should always be greater than the amount of gas put into the system as a percentage of the oxygen in the air is consumed during combustion.

Combustion Retarding Apparatus.

The manometer valve is now closed, the pet cock on the spark plug opened, the aspirator and compressed air valves opened. The aspirator should be filled and drained three or four times to insure the complete removal of all burned and unburned gases.

If the sample proves effective in retarding combustion a richer mixture is introduced into the system and the sample tested as above.

When the screen fails to retard at a certain percentage mixture, a test using this same mixture is repeated to make reasonably sure at what mixture the screen has failed. Then a new sample is installed and the process repeated as above.

By finding at what percentage mixture the different samples prove ineffective and comparing these values with those found for the other screens and plates, a relativity

Combustion Retarding Apparatus.

may be established between the samples tested. In this manner, the most efficient screen may be found.

FIG. NO. 8 SAMPLES AFTER TEST.

Combustion Retarding Apparatus.

The following samples were tested,- a picture of these is shown in figure 9, with their respective numbers:

Screen No.	Mesh	Gauge	Material
1	20	30	Cu.Plate
2	16	28	Brass
3	20	30	"
4	50	37	"
5	4" German Silver Corrugated Coil		
6	60	36	Copper
7	40	35	Brass
8	60	36	"
9	24	35	Copper

Combustion Retarding Apparatus.

DATA.

Volume of System = 6 gallons 3.667 pints.

1 gallon = 231 cu.in.

1 pint = 28.88 cu.in.

6 x 231 = 1,386 cu.in

28.88 x 3.667 = 105.9 cu.in.

Volume 1,491.9 cu.in.

1 cu. in.= $\overline{2.54}$ 3 cm.= 16.38 c.c.

1,491.9 x 16.38 = 24,430 c.c. volume of system.

% Gas	% x Volume	Gas, c.c.	Air, c.c.
7	.07 x 24,430	1720	23,710
8	.08 x "	1955	22,475
9	.09 x "	2200	22,230
10	.10 x "	2443	22,000
11	.11 x "	2685	21,780
12	.12 x "	2930	21,500
13	.13 x "	3180	21,250
14	.14 x "	3420	21,010
15	.15 x "	3660	20,800
16	.16 x "	3910	20,520
17	.17 x "	4150	20,380

Combustion Retarding Apparatus.

DATA.

% COMPOSITION OF ILLUMINATING GAS.
(As secured from the
Engineers of the Peoples
Gas Light & Coke Co.)

Name	Formula	%
Carbon Dioxide	CO_2	3.5%
Ethylene	C_2H_4	
Propylene	C_3H_6	12.0%
Benzene	C_6H_6	
Naphthalene	$C_{10}H_8$	
Oxygen	O_2	.5%
Carbon Monoxide	$C\ O$	29.0%
Hydrogen	H_2	31.0%
Methane	$C\ H_4$	19.0%
Nitrogen	N_2	5.0%
Total		100.0%

Combustion Retarding Apparatus.

DATA.

% Gas	% x P_2	Loss # sq.in.	Manometer In.Hg.
7	.07 x 14.7	1.03	2.1
8	.08 x "	1.175	2.4
9	.09 x "	1.32	2.79
10	.10 x "	1.47	2.99
11	.11 x "	1.62	3.31
12	.12 x "	1.715	3.49
13	.13 x "	1.910	3.89
14	.14 x "	2.060	4.20
15	.15 x "	2.203	4.50
16	.16 x "	2.350	4.8
17	.17 x "	2.500	5.1

29.9 in.Hg. = 14.7# sq.in

$$1\# \text{ sq.in} = \frac{29.9}{14.7} \quad 2.03 \text{ in.Hg.}$$

1.03 x 2.03 = 2.1 in.Hg.

Combustion Retarding Apparatus.

DATA.

DETERMINATION OF EXPLOSIVE RANGE AND DECREASE IN VOLUME AFTER COMBUSTION.

Explosive Range		Volume Decrease	
P_1 In.Hg	% Gas Mixture	InHg.	% Decrease
1.00	3.33	1.00	No Combustion
1.20	3.99	1.20	" "
1.40	4.66	1.40	" "
1.80	5.99	1.80	" "
2.00	6.95	2.00	" "
2.12	7.06	2.75	9.25
2.50	8.25	3.25	10.8
3.00	10.03	3.50	11.7
3.50	12.00	3.75	12.5
4.00	13.55	4.75	15.8
5.12	17.00	5.75	19.25
5.2	17.21	5.2	No Combustion
5.3	17.39	5.3	" "

The lower limit was found to be 7.06% and the upper limit 17.00%.

Combustion Retarding Apparatus.

DATA.

TEST OF SCREEN #6- FIGURE 9.
60 Mesh #36 Gauge Copper Wire Screen.

P_1 In.Hg.	% Gas Mixture	Observed Combustion. Head End	Rear End
2.12	7.06	Yes	No
2.20	7.33	"	"
2.25	7.43	"	"
2.40	8.00	"	"
2.50	8.25	"	"
2.60	8.48	"	"
2.70	* 8.61	"	Yes
2.75	8.95	"	"
3.00	10.03	"	"

SCREEN #8- FIGURE 9.
60 Mesh #36 Gauge Brass Wire.

2.5	* 8.25	Yes	Yes
2.60	8.48	"	"
2.75	8.98	"	"

* When Combustion appears at both head and rear ends, it means the sample proved ineffective.

Combustion Retarding Apparatus.

DATA.

TEST OF SCREEN #4- FIGURE 9.
50 Mesh #37 Gauge Brass Wire Screens.

P_1 In.Hg.	% Gas Mixture	Observed Combustion. Head End	Rear End.
2.12	* 7.00	Yes	Yes
2.25	7.50	"	"
2.50	8.25	"	"

SCREEN #7- FIGURE 9.
40 Mesh #35 Gauge Brass Wire.

2.12	7.00	Yes	No
2.25	7.50	"	"
2.50	8.25	"	"
2.62	8.50	"	"
2.75	8.91	"	"
2.90	* 9.91	"	Yes
3.00	10.10	"	"
3.12	10.26	"	"
4.00	13.30	"	"

* When Combustion appears at both head and rear ends it means the sample proved ineffective.

Combustion Retarding Apparatus.

DATA.

TEST OF SCREEN #3- FIGURE 9.
20 Mesh #30 Gauge Brass Wire Screens.

P_1 In.Hg.	% Gas Mixture	Observed Combustion. Head End	Rear End.
2.12	7.06	Yes	No
2.20	7.33	"	"
2.40	8.00	"	"
2.62	8.50	"	"
2.75	8.98	"	"
2.80	* 9.01	"	Yes
3.00	10.03	"	"

SCREEN # 2- FIGURE 9.
16 Mesh #28 Gauge Brass Wire.

2.12	7.06	Yes	No
2.20	7.33	"	"
2.25	7.43	"	"
2.50	* 8.25	"	Yes
2.75	8.98	"	"
2.80	9.01	"	"

* When Combustion appears at both head and rear ends it means the sample proved ineffective.

Combustion Retarding Apparatus.

DATA.

TEST OF SCREEN #9- FIGURE 9.
24 Mesh #35 Gauge Copper Wire Screens.

P_1 In.Hg.	% Gas Mixture	Observed Combustion. Head End	Rear End
2.12	7.06	Yes	No
2.20	7.33	"	"
2.40	8.00	"	"
2.50	8.25	"	"
2.65	8.53	"	"
2.75	* 8.98	"	Yes
3.00	10.03	"	"

PLATE #1- FIGURE 9.
Copper Plate - 20 perforations per inch.

2.12	7.06	Yes	No
2.40	8.00	"	"
2.50	8.25	"	"
2.62	8.50	"	"
2.75	* 8.98	Yes	Yes
2.80	9.01	"	"

* When Combustion appears at both head and rear ends it means the sample proved ineffective.

Combustion Retarding Apparatus.

DATA.

TEST OF SAMPLE #5- FIGURE 9.
German Silver Corrugated Coil.

P_1 In. Hg.	% Gas Mixture	Observed Combustion. Head End	Rear End.
2.12	7.06	Yes	Yes
2.40	8.00	"	"
2.50	8.25	"	"
2.62	8.50	"	"
2.75	8.98	"	"

This coil failed to retard combustion at the lowest percentage mixture obtainable. This may have been due to the fact that it was difficult to secure a tight fitting of the coil into the pipe wall.

Combustion Retarding Apparatus.

SUMMARY OF RESULTS.

Screen #	% Mixture at failure	Damage to Sample
7	9.91%	Mesh Slightly distorted.
3	9.05%	Slightly burned.
9	8.98%	" "
1	8.98%	" "
6	8.50%	" "
2	8.25%	" "
4	Screen entirely burned away.	
8	" " " "	
5	No Retardation-Sample undamaged.	

The relative values of these samples will be discusses very explicitly in part 3 - also the reasons for the failures of these samples will be explained in the same section.

PART 5

A RESTATEMENT OF THE PROBLEM AND A DISCUSSION OF THE VARIABLE FACTORS.

Combustion Retarding Apparatus.

RESTATEMENT OF THE PROBLEM AND A DISCUSSION OF THE VARIABLE FACTORS.

The effectiveness of the retardant material depends upon its ability to absorb a sufficient amount of heat from the flame wall as it passes thru the mesh of the retardant. That is the retardant material must take enough heat from the flame wall to reduce it below its ignition temperature.

Every explosion of gas and air even the smallest, is accompanied by the liberation of heat: as the chemical reaction progresses it is followed by an increase in the amount of heat, which in turn helps to accelerate the reaction: and thus the two advance together, both in highly intimate connection and mutually helpful, until the entire mass of the substamce has been heated and chemically converted.

When the spark from the coil is placed in contact with an explosive mixture of gas and

air, the flame from the spark produces ignition at the point of contact, i.e. incites chemical reaction. This combustion proceeds towards the center of the apparatus and thereby forms a plane of combustion which divides the gaseous mixture into two parts; on the one side are the highly heated products of combustion, and on the other is the still unconsumed gas. The dimensions of the two parts vary in proportion as combustion moves from the consumed to the unconsumed portion.

The velocity at which this plane advances is different for each gaseous mixture, and depends both on the composition of the mixture and on the pressure to which it is subjected, the higher the velocity the greater the rise in temperature, and this latter in turn directly influences the expansion of the gas and the products of combustion, which thereby exert such a strong pressure on their environment (air, walls, etc.)

Combustion Retarding Apparatus.

that the containing vessel would probably be ruptured. This excess pressure is taken care of by a relief valve.

The velocity of propagation of the plane of combustion thru explosive mixtures of gas is often extremely rapid, and the phenomena produces a vacuum, in consequence of which, and of the action of the external atmospheric pressure on the walls, the latter collapse inwards, towards the site of the explosion, instead of being thrown down in an outward direction. This phenomena was noted very carefully and its magnitude measured by the difference in pressure registered on the Manometer, and reference to curve No.4.

The results obtained in this experiment show that screen No.7, figure 9, which is 40 mesh 35 gauge brass wire, gave the best results, retarding the combustion until the percentage gas mixture reached 9.91%.

Combustion Retarding Apparatus.

Screen #3- figure 9- a 20 mesh 30 gauge brass wire was second in retarding value, failing when the percentage mixture reached the value of 9.05%.

Screen #9- figure 9 - a 24 mesh, 35 gauge copper wire retarded the combustion up to 8.98%.

Plate #1- 20 mesh, 30 gauge copper plate retarded the combustion up to 8.98%.

Screen #6- 60 mesh, 36 gauge copper wire failed when the mixture was 8.50%.

Screen #2- 16 mesh, 28 gauge brass wire retarded the combustion up to 8.25%.

Screen #3- 50 mesh, brass wire and #8 a 60 mesh, brass and the German Silver Coil did not retard any combustion. The flame burned away that part of screens #4 and #8 which were in actual contact with the flame.

From the foregoing results, it is indicated that the fineness of the mesh alone will

Combustion Retarding Apparatus.

not retard combustion unless the wire in the screen have a greater cross sectional area than those tested by the writers.

A combination of these two features would necessitate the construction of a special mesh and special gauge screen. This may be accomplished by having the cross section of the wire, elliptical or rectangular in place of circular, giving a greater body to the retardant and at the same time maintaining a very fine mesh.

The writers feel absolutely certain from the results obtained in these tests that a series of baffle plates of high heat conductivity placed short distances from one another and imbedded in the pipe wall would be the most effective way of retarding combustion in closed pipes.

As the explosive mixtures used in this experiment were at rest, the samples were given a more rigid test than if the mixture was in

motion and the sample placed on the down-stream portion of the pipe. Therefore, all of these samples would hold up much better in actual field work, but their relative values as found in these tests would not be altered.